A Technical Analysis to Identify Ideal Geographic Locations for Tropical Testing of Army Materiel and Systems

July 1998

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This report presents the findings of a scientific panel assembled by the Army Research Office at the request of U.S. Army Yuma Proving Ground, for the purpose of identifying alternative locations for tropical testing should the Army be required to relocate from its current facilities in Panama. The panel addressed this tasking in three sequential steps. 1) The mission for tropical testing was examined to define the conditions that best provide the environmental challenges needed for tropical testing at present and into the next century. 2) The defining parameters for the ideal tropical test environment were identified and categorized into three grouped factors of climate, physical setting, and biotic character. 3) Regions of the world were identified that best fit the combined parameters for an ideal tropical test environment. The analysis was based solely on critical environmental parameters defined by the panel, without constraining the analysis by the numerous other non-scientific considerations that would impact any final site selection. To support any follow-on siting efforts, a decision tree was constructed based upon a prioritization of the critical environmental parameters.

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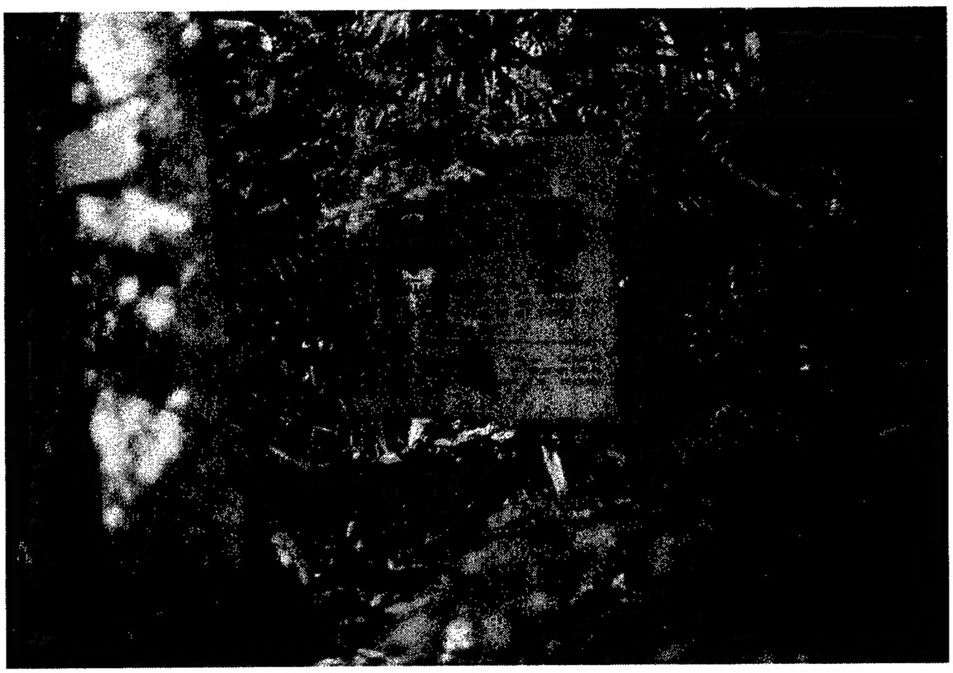

This analysis was conducted by a scientific panel assembled by the Army Research Office and Yuma Proving Ground of the US Army Test and Evaluation Command

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EXECUTIVE SUMMARY

This report presents the findings of a scientific panel assembled by the Army Research Office at the request of the Technical Director, US Army Yuma Proving Ground, for the purpose of identifying alternative locations for tropical testing should the Army be required to relocate from its current facilities in Panama. The panel addressed this tasking in three sequential steps. First, the mission for tropical testing was examined to define the conditions that best provide the environmental challenges needed for tropical testing at present and into the next century. Next, the defining parameters for the ideal tropical test environment were identified and categorized into three grouped factors of climate, physical setting, and biotic character. Finally, regions of the world were identified that best fit the combined parameters for an ideal tropical test environment. The analysis was based solely on critical environmental parameters defined by the panel, without constraining the analysis by the numerous other non-scientific considerations that would impact any final site selection. To support any follow-on siting efforts, a decision tree was constructed based upon a prioritization of the critical environmental parameters.

As detailed in Table 6 and illustrated in Figure 6 of this report, areas considered as primary candidates for Army tropical testing can be divided into two groups: (i) locations which meet all of the critical environmental conditions defined by the panel for an ideal test site and (ii) locations which provide the majority, but not all, of those requisite conditions. The first group of six locations in Table 6 are listed in order of relative proximity to the continental US, includes: northern Honduras, the Isthmus of Panama, coastal French Guyana/northeastern Brazil, the southwestern New Guinea Lowlands, low-moderate altitude areas of the East Indies in east-central Java and southeastern Borneo, and the Isthmus of Kra in Malaysia. The top two localities from this premier group are the Isthmus of Panama and the Isthmus of Kra because both areas offer a spectrum of tropical conditions and environments within a compact geographic area. The second group of ten locations in Table 6, consists of coastal Belize, Puerto Rico, southeastern Costa Rica, northwestern Colombia, portions of the Hawaiian Islands and the Fiji Islands, the Philippines, New Britain-New Ireland, the York Peninsula of northeastern Australia, and the Bangkok area of coastal Thailand. These are areas that exhibit the general physiographic and biotic character required for an ideal test site, but fail to provide one or more of the critical elements of climate that define the warm, humid tropical environment.

This analysis was limited to the regional scale due to a lack of site-specific data and to the time constraints established for the study. Although some 15% percent of the earth's land surface is tropical in general character, it is clear from Figure 6 that very little of this area is considered ideal for tropical testing. Most germane to our purpose is the recognition that no site in the continental United States, the Caribbean sea islands, or the south-central Pacific region meets the full set of criteria established by the panel for the ideal tropic test location. Furthermore, only isolated areas within US political jurisdiction or influence could support even limited tropical testing.

Another salient feature of this study is that the panel began by developing a set of suitability criteria on the basis of desirable environmental factors and then used these to identify specific areas of the world suitable for the test mission. This approach differentiates this study from others that

have considered the relocation of the Army Tropic Test Center from its present site within the canal-zone region of Panama. Therefore, the fact that Panama was observed to be a very strong fit to the idealized tropical test facility of the future is important because it verifies the use of data from the numerous analog studies done which have compared Panama with other sites around the world. However, some caution is necessary in examining these earlier studies because they are based solely upon climate parameters and these parameters do not completely define the ideal tropical test environment. The overall conclusion from this study that both the scientific data and practical considerations support Panama as an optimum site for the testing of Army materiel, systems, and human performance has direct management implications. Within Panama, the Atlantic side of the isthmus at Fort Sherman provides the necessary climate conditions, the varied physiographic settings, and the biological communities that define an idea tropical test area. **Therefore, the study panel considers that negotiating with the government of Panama to continue the Army tropical test mission in Panama, within the terms and conditions of the Cater-Torrijos Treaty when implemented at the end of 1999, is a more attractive option for the Army than all other possibilities considered by the panel during its discussions and deliberations.**

In summary, the study panel has defined the ideal tropical test environment in measurable parameters and identified locations worldwide exhibiting these conditions. The approach taken has provided an analysis tool that will help to identify tradeoffs resulting when planners apply practical constraints in evaluating specific alternative sites for the Army tropical test activity. No further work is recommended by the panel to achieve the goals it was assigned. However, it is the strong opinion of the study panel that specific locations, which might be considered in the future as candidates for an alternative tropical test site, be analyzed in much greater detail than could be accomplished in this study utilizing the criteria and that the decision tree approach developed by the panel as the template for such detailed site investigations. This approach, with modification, could also be applied to test and validate the suite of natural environments important to Yuma Proving Ground and the US Army.

TROPIC TEST CENTER RELOCATION STUDY

I. BACKGROUND

I.1. Introduction

Since 1960, some 75 percent of all international and internal conflicts have been in countries whose land masses are totally or partially in the tropics. The major military powers of the world recognize the need for field testing of materiel in the tropics. The US experience in the Pacific in World War II and in Southwest Asia during the Vietnam conflict clearly demonstrated the need to test the performance of new equipment under the harsh tropical environmental conditions.

As prescribed by regulation (AR70-38), and defined by requirements in numerous performance standards (MIL STDs), environmental conditions and their effects are to be given realistic consideration in the research, development, test, and evaluation (RDT&E) process for material used in combat by the Army. As a result, testing and evaluation of materiel, systems, and human performance in the tropical environment is well established and has a long history. The mission of testing materiel in extreme natural environments for the Army is vested with the US Army Yuma Proving Ground (YPG). Presently, this mission is accomplished at desert and arctic test facilities in the United States and at a tropical test facility in the former Canal Zone area of the Republic of Panama. Army materiel testing in the canal area of the Republic of Panama dates as far back as WWI. Since that time, the mission has evolved into its present form with the establishment of the Tropic Test Center (TTC) in 1962 and subsequent redesigns of the specific test functions in response to evolving military needs throughout the years.

I.2. Study Panel Tasking

Under the terms of the Carter-Torrijos Treaty of 1977, elements of the military mission in Panama are required to relocate from the country by December 31, 1999. As a result of this requirement, YPG requested the assistance of the US Army Research Office (ARO) to convene an expert panel to examine the scientific issues related to the relocation of the Tropical Test Center (TTC) function. The membership of the study panel assembled by ARO, together with a brief statement of qualification for each member, is listed in Appendix I; the tasking for the panel is described in Appendix II and summarized in the following paragraph.

The charter of the scientific panel, presented in Figure 1, was to identify areas of the world suitable for the natural environmental testing and evaluation of military materiel and systems under tropical conditions. The tropical environment is the most diverse and complex natural environment in the world and, at the same time, is one of the most challenging for soldiers, equipment, and systems. Modern sophisticated systems, with complex integrated electronic circuitry are more critically effected by tropical factors than the simpler electromechanical systems of the past. The effects of

Figure 1. YPG charter for the Tropic Test Center relocation study panel.

PEER PANEL CHARTER

Within the context of the possible relocation of the US Army Yuma Proving Ground Tropical Test Center under the provisions of the Carter-Torrijos treaty of 1977, the scientific peer panel will identify and independently evaluate potential areas of the world that would offer the combination of environmental conditions, analogous to those present in the Canal Zone of Panama, where the testing and evaluation of Army materiel, equipment systems could be accomplished under a variety of tropical conditions. The geographic limits for consideration are c. 22°N-20°S, 95°E-30°W (including Panama). General considerations are to include climate, physical and ecological setting, and other environmental characteristics to adequately challenge equipment and systems in a tropical environment. Factors to be considered are fisted below. Spatial variability and accessibility are issues of major importance. Additionally, YPG has embarked on a "Virtual Proving Ground" initiative that will develop synthetic environments in which testing can be undertaken. The basis of the VPG will be "Master Tropical Environment Reference Sites" that will encompass many common environmental factors, with a strong synergism. The peer panel should also give due consideration to this requirement in their alternative area deliberations.

TEST AREAS

Long Term Exposure Sites:

I. (i) Inland (open & jungle) (ii) Coastal: (open, breakwater, & submerged)

II. Human Factors Test Area: 200+ acres to operate standardized courses measuring human response under tropical conditions while performing repetitive tasks with new equipment or techniques.

III. Field Training Area: 400-1600 acres (2kM2) of open and mixed jungle terrain, including streams
(i) operational testing for small unit to company size units to evaluate equipment and soldier performance
(ii) developmental environmental durability and performance testing of communications, electronics, & chemical/biological defense equipment

IV. Vehicle Mobility Sites (amphibious, coastal, mangrove swamps, savannahs, forest/jungle having trails with stream crossings)

V. Master Environmental Reference Sites

VI. Firing Range

ENVIRONMENTAL FACTORS

Climate	Meteorology	Seasonality	Solar Radiance
Winds	Temperature	Relative Humidity	Fog
Precipitation	Topography	Hydrology	Geology/Soils
Vegetation	Micro/Macro-biota (biomes)		Salt Spray

heat, humidity, direct insolation, corrosive salt fog, and biological factors (such as bacteria and fungus) - coupled with a dense jungle canopy - not only attack and degrade equipment, but create a hostile natural environment in which the soldier must field the technology to accomplish a mission.

An important consideration for the successful completion of this study was for the panel to fully understand the testing mission and process. Therefore, military personnel and individuals with a military background, who were familiar with the Army requirement for military equipment testing and could articulate this knowledge, were specifically included in the panel. The panel meeting included visits to TTC field sites and briefings by TTC staff in order to provide the panel with a practical understanding of the specifics of tropical testing and how it must be conducted. A briefing presented by the Jungle Operations Training Center greatly enhanced understanding of military training and operations in the tropical environment.

The initial task of the panel was to examine its scope of work in the context of a vision of both present tropic testing activities and future requirements. There was a twofold reason for this approach. First, it recognizes that the many previous analog studies regarding relocation of the tropical test function (listed in the bibliography to this report) were based on the unproven assumption that Panama defined the standard for Army tropic testing against which alternatives should be compared and evaluated. Second, these studies were based on a dated testing mission for the TTC. In the context of conducting an "honest-broker" study and taking an unbiased approach to the relocation issue, the panel considered that its deliberations should not begin with these same precepts. This is not to imply that the study panel was critical of the previous work, but rather that an evaluation and confirmation of all assumptions and consideration of up-to-date information and data was the most appropriate starting point for its study.

I.3. Overview of the Testing Process

The testing and evaluation of equipment and systems in the natural environment is conducted using accepted laboratory protocol and established engineering practices. This assures repeatability, experimental control, and validation of test results. Many aspects of the testing process are conducted over long periods of time and, therefore, a fundamental requirement for a test facility is the presence of tropical conditions on a year-around basis. Testing also requires a well-characterized and understood suite of tropical field sites that provide environments that are fully representative of those in which soldiers, systems, and materiel may be fielded during combat. These test sites must, in turn, be capable of efficiently accommodating broad categories of military systems and test activities. Historically, environmental testing at TTC, which is described in USATTC Report 79040, has met this requirement. This testing has been divided into three broad categories:

(i) long-term tropical exposure testing of material, equipment and munitions;

(ii) technical performance and reliability testing of equipment and systems under tropical conditions; and

(iii) system and human performance evaluation under tropical stress (i.e. human factors testing).

In addition to the ongoing testing requirements in these three areas, a vision for future requirements includes testing of new technologies for *Force XXI* and the *Army After Next*. This testing would include: sensors (airborne/space-born and man-portable systems); information, data networking, and communication technologies based on electromagnetic transfer; cloaking and reduced signature technologies; and product improvements of existing systems (as a cost saving measure to replacement systems). New systems, such as Land Warrior, spearheaded by PM Soldier, will provide the individual soldiers with advanced technologies and weapons for the battlefield of the 21st century. Additionally, there will be increased focus on dual-use or multi-use technologies that have high pay back, such as environmental technologies for UXO detection/location and similar applications. All of these technologies are highly sophisticated and complex. As such, test and evaluation of such new technology will require a thorough understanding of the environmental factors affecting their technical performance as well as the synergistic environmental effects that challenge equipment operability and reliability.

Future test technologies to assess performance will require increased sophistication, one aspect of which will be the increased reliance on modeling and simulation in the virtual environment to support test and evaluation. Additionally, the test community will have greater flexibility in meeting customer requirements for test data and evaluation through new approaches to modeling and simulation. Development of digital environmental reference models for modeling and simulation is currently under development as a series of Master Environmental Reference Sites (MERS), which are located at extreme climate test sites under the command of YPG. These carefully characterized MERS are the reference environmental sites for the Virtual Proving Ground (VPG).

Geographic proximity of test/reference sites is another critical issue. This need is driven by two linked considerations: (i) the diversity of the operational and support requirements for tropical testing, both the present and the future, and (ii) the requirement for a variety of different representative tropical environments for future virtual testing. Test sites scattered across a wide geographic area, or a split-base site situation in two or more distant locations, would not be a tenable option because of high costs associated with infrastructure, instrumentation, and logistics, as well as the difficulty associated with integrating test activities. Although this issue is not directly related to the evaluation of tropical environments suitable for the general test mission and requirements, the panel considered it to be an important, overarching factor that directly influenced its deliberations and decisions.

II. DESCRIPTION OF THE STUDY

II.1. The Study Plan

The panel tasking was described in paragraph I.2. This discussion focused on the need to base the panel analysis on a fundamental description of the ideal tropical environment that would address the mission for tropical testing into the next century. The set of environmental criteria arising from

this analysis would then provide the basis for identification of areas of the world suitable for conducting the Army tropical test mission. Subsequently, others could use these criteria as objective measures against which to evaluate candidate test center locations. The scope of work for the panel from Figure 1 is further articulated in terms of specific tasks in the following three paragraphs.

II.1.A. Description of the Ideal Tropical Test Site

This task standardized the approach for selecting alternative locations for Army tropical testing and differentiated it from one of simply identifying locations elsewhere which replicated the temperature and rainfall conditions present at the current TTC sites in Panama, as had been the approach in previous analog studies (Blair, 1958a, b; Chambers, et al, 1958; Thompson, 1958 a, b, c; Blair and Chambers, 1959, Thompson, 1959; Anstey, 1960; Chambers, 1960). Thus, the panel first determined what would constitute the optimum environmental setting for tropical testing and then, based upon this determination, developed a list of specific climatic, geophysical, and biological criteria to characterize the ideal tropical test environment. Development of an ideal test environment model would serve a basis for all follow-on siting work and also should be useful in all continuing operations for the TTC, regardless the ultimate site selected. The ideal test site will be defined on the basis of a set of summary parameters that describe: (i) Climate, (ii) Physical Setting, and, (iii) Biological Character.

II.1.B. Definition of Summary Parameters

The panel identified a set of hierarchical summary parameters related to the three boundary conditions (climate, physical setting, and biological character) to define the ideal tropical test environment. The template that resulted from this process was then used to identify regions of the world that could meet the individual criteria. The next step in the panel process was to overlay the results to identify the geographic regions that best meet the established criteria. This two-step process established a hierarchy of the parameters first within the three criteria and then compiled a derivative hierarchy based upon all major parameters of the three criteria.

II.1.C. Site Selection Considerations

It was determined that infrastructure elements, geopolitical considerations, or economics would not to be used to place restrictions on location identification because such issues touch upon considerations of policy. Practical concerns of significance identified by the panel members during the course of their deliberations are presented and briefly discussed in Paragraph **V, SPECIAL CONSIDERATIONS.** These include those issues associated with continued operations in Panama as well as concerns related to relocation options. The importance of having the ideal site model as a standard is clarified as these practical considerations come into play. Such matters as cost and support infrastructure may force tradeoffs in site selection, and the ideal site model will be an important tool in understanding and evaluating the impacts of any tradeoff that might be considered. To assist in further siting studies, a decision matrix was constructed to conduct any trade-off analyses.

III. TECHNICAL ANALYSIS

III.1. Background

In general, the tropical regions of the earth lie within 2,570 km of the equator, i.e. between 22.5° N and 22.5°S latitude. The specific boundaries of areas considered to be tropical in nature depends on the interplay of ocean currents and atmospheric circulation patterns with the major continental land masses. Overall, the tropics include some 15% of the earth's land surface and 53% of countries and territories worldwide contain areas of tropics. The climate of the tropics is dominated by equatorial and tropical air masses and characterized by warm temperatures. Climate classification systems that combine the characteristics of temperature and precipitation define the tropics as regions in which average monthly temperatures are in excess of 18 (64°F), where there is no winter season, and in which annual rainfall is large and exceeds annual evaporation (see. e.g. Strahler, 1967). Daily temperature ranges in the tropics may be up to 17°C, whereas mean monthly ranges are on the order of only 1.5°C. Precipitation within the tropics is significantly more variable than temperature and, therefore, the major climatic differences that occur within the tropics are more appropriately described in terms of precipitation pattern. For example, low-latitude climates controlled by equatorial and tropical air masses are divided into 5 major subgroups in the Köppen-Geiger (1938) system of climate classification: (i) the Equatorial Rainforest Climate, (ii) the Trade-Wind Littoral Climate, (iii) Tropical Savanna, (iv) Tropical Steppes and Deserts, and (v) West Coast Desert Climate. The rainy tropics (subgroups i and ii), characterized by a rainfall in excess of 2000mm/yr, are situated in the equatorial lowlands and along coasts exposed to the warm and moist easterly trade winds. The wet-and-dry tropics (subgroup iii) are situated on the westward and poleward sides of the rainy tropics between 5-25° N and S latitude. In these regions, precipitation is less intense than in the rainy tropics, with annual precipitation between 750-1800mm, and has a distinctly seasonal character. Typically, the wet-and-dry tropics have a winter dry season, which increases in length poleward away from the equator. Tropical steppes and deserts (subgroups iv and v) tend to occur on the western coasts of continents, due to the influence of cool ocean currents and dry winds that occur on the eastern sides of the subtropical high-pressure gyres.

Tropical regions can be broadly divided into three end-member physiographies: high-relief ocean islands and coastal regions typically in a neo-volcanic setting, flat atoll-type islands or low-gradient river basins, flood plains and deltas, and elevated savanna. In general, the high-relief tropics is characterized by sandy beaches, a coastal plain of variable width, and a rugged interior topography. The low-relief tropical river basins typically meander across wide areas, with thick vegetation upstream and backwater and coastal swamps near the coast. Upland regions of tropical savanna are grasslands developed upon rolling hills and plateau that are deeply cut by channels and gorges. Soil profiles are well developed in the wet tropics, with strongly-leached lateritic soils characteristic of this climate. By contrast, soils in the dry tropics tend to be coarser, better drained, and less lateritic in character. Vegetation in the wet tropics is primarily, but not exclusively dense tropical rain forest (jungle). Multiple canopies are common and stem spacing is significantly less than in mid-latitude forests. By contrast, the dry tropics tend to be characterized by extensive grasslands, interspersed with areas of shrubs and short trees, that lack the multi-canopy vegetation and the vegetation debris and ground litter that is a common feature of the rain forest.

In terms of Army materiel testing requirements, AR70-38 classifies the world into four Climatic Design Types and subdivides each basic type into one or more daily weather cycles. AR70-38 further mandates tropic testing in the two daily cycles of temperature, solar radiation, and humidity that characterize the humid tropics (i.e. the "wet-hot" and "wet-warm" daily cycles). These conditions occur throughout the year, with little or no seasonal variation, in regions of Equatorial Rainforest Climate and Trade-Wind Littoral Climate (i.e. the "wet tropics"), the former prevailing under jungle canopy and the latter manifest in more open areas.

III. 2. Overarching Requirements

In the view of the study panel, the requirements defined above are best met in terms of a location in which the different testing activities are conducted within a relatively small (c. 200 to 300 km^2) geographic area. Ideally, this area would exhibit variable conditions of climate (e.g., frequency/distribution of precipitation and temperature) across the spatial domain encompassing the testing activities and be characterized by a variety of distinct topographic and vegetative environments (e.g. coastal-lowland-upland, broadleaf rain forest-savanna) that are transitional from one to the next. The area should not be a high-risk zone in terms of frequency of natural hazards (e.g. tropical storms, volcanic activity, earthquakes, landslides, etc.). Also, it should not be affected by significant adverse anthropogenic activities (e.g. high adjacent population density, upstream pollution from urban, industrial, and/or farming activities) that could have a negative impact on testing. The geographic limits established in the initial tasking to the panel eliminated Africa and the Indian subcintinent from consideration.

III.3. Climate Requirements

III.3.A. Fundamental Climate Discriminators

Wet, humid tropical conditions may be constrained according to the mean monthly temperature, relative humidity, and precipitation threshold considerations listed in Table 1. The bounds on temperature for climate testing listed in AR 70-38 lie within the ranges defined above. Areas of "wet-hot" climates have air temperature ranges from 27-35°C (equating to 81-95°F) and humidities ranging from 75-100%, whereas those with "wet-warm" tropical regimes have near-constant temperatures and humidities, temperatures exceeding 24°C (75°F), and humidities of order 95-100%. In both cases, mean annual precipitation exceeds 2,000 mm (80 inches). Threshold limits for human factors testing are 30°C (85°F) in dry heat, or 25°C (77°F) in extremely humid conditions. Minimum bounds defined here describe the wet tropical regions of the globe that occur within the zones of Equatorial Rainforest Climate and Trade-Wind Littoral Climate; maximum limits were assigned based on perceived requirements for acceptable materiel testing and for practical operational conditions. For example, annual rainfalls higher than 6,000 mm would likely make large areas impassable for long periods, whereas areas of climatic seasonality where winter temperatures drop below 15°C would be unsuitable for testing. The upper bounds listed in Table 1 should not be applied strictly to a single location, but rather should be used as a threshold guide for site-averaged values of each parameter.

Table 1. Threshold bounds on monthly averaged values for potential wet tropical locations.

	Ambient Temperature (^{o}C)	Ambient RH (%)	Precipitation
Minimum	18-20	60	100 mm/month
Mean to exceed	27	75	2000 mm/year
Mean bounded by	40	100	6000 mm/year

III.3.B. Variability Aspects

Long-term climate and local weather variability will impact the range of temperature, precipitation, and relative humidity conditions manifest at any particular site, as well as the predictability of these parameters. Time scale effects of minutes to years may impact a study, however, only time-scale variation on the order of a day or longer are well captured by present climatic data sets. Descriptions and desirability of diurnal, seasonal, and interannual variability of the ideal tropic test site are presented below. Seasonality is not considered to be a requirement for this mission, but a brief dry season (such as that which is characteristic of the Trade-Wind Littoral Climate regime) is not viewed as detrimental.

Diurnal variability of temperature, relative humidity, and rainfall are characteristic of much of the wet tropics. Highly vegetated (under canopy) regions are typically far less variable on these time scales. In the tropical regions of the continental interior or on large islands, the maximum temperature and minimum in relative humidity occur somewhat after local noon, with peak rainfall intensity in the late afternoon. By contrast, the precipitation maximum on small islands or atolls tends to occur in the late night or early morning.

In the near-equatorial belt (with the exception of some Indian Ocean regions), there is little seasonality in climatic parameters. Increased seasonality (i.e. distinction between "wet" and "dry" seasons) becomes evident farther from the equator, with monsoon regimes dominating poleward of about 10° N and S latitude in the warmer waters of the western ocean basins. Associated with the monsoons, is increased tropical cyclone (and hence hurricane or typhoon) activity. Eastern ocean basins typically have cooler ocean temperatures and broad regions of suppressed intense convective rain. During the dry season, precipitation totals not less than 5-10% of the annual rainfall total are maintained in a true wet tropical regime.

The effects of the El Niño/Southern Oscillation (ENSO) have been documented in the recent literature. Whilst regional impacts of this coupled atmosphere/ocean phenomenon vary greatly with both the intensity of the ENSO event and geographic location, strong responses in most of the wet tropics have been documented. Onset of an ENSO event is typically occurs mid-late in the calendar year, peaking around January of the following year. While the effects of an ENSO event seem to be linked into the annual cycle, these onset and retreat dates may vary in the same way as the onset and retreat of the regional summer monsoons.

III.3.C. ENSO Effects

The broad response to ENSO in the Central America/Caribbean region is a decrease in the dry season ("winter") rainfall and decreased wet season tropical storm activity. Since tropical storms are also a rainfall source, annual precipitation can drop significantly in these regions. Local ocean temperatures in the eastern equatorial Pacific rise by up to 4-5°C above the norm. Farther into South America, both droughts and floods occur. During an ENSO event in the Tropical Western Pacific the center of peak convective rainfall activity - from local thunderstorm systems up to tropical storm activity - shifts eastward from its climatological location in the western Pacific basin. Shorter and drier rainy seasons are observed over most of Southeast Asia, including the maritime continent and tropical Australia. Central Pacific locations, such as the Hawaiian and Fiji Islands, experience greatly enhanced tropical cyclone (typhoon) activity in these years.

Seasonal forecasts predicting onset and potential duration of individual ENSO events are becoming more skillful and tracking of tropical ocean temperatures and surface pressures allow mapping of ENSO intensity evolution. Choice of a tropical test site should include some effort to quantify the response of the local climate variations to ENSO. This information could be used to formulate an additional selection criterion to apply to sites that fulfill the primary site selection criteria or may be useful in guiding operations at a specific location.

II.3.D. Tropical Storm Activity

The important constraint of a location choice to regions not affected by tropical storm activity on a routine basis essentially confines the choice to land areas within a few degrees of the equator. Because many regions with some exposure to tropical storms actually experience very infrequent storm passage, absence of all threat from tropical storms is an extreme constraint. Minimizing tropical storm exposure while meeting other requirements is the approach adopted by the panel.

III.3.E. Climate Summary

Taking all of the above considerations into account, at least 17 areas worldwide are readily identifiable that exhibit climatic conditions desirable for a tropical test center (Table 2). Potentially significant weather and climate related factors of a negative nature are described below. These will be used as secondary filters in analyzing climate data to focus the location selection. The fundamental descriptors of the wet tropics (temperature, precipitation and relative humidity) are used here as a

Table 2: Suitability rating for candidate locations resulting from the general climate analysis. The primary factors of average annual temperature (T), average annual precipitation (P), and percent relative humidity (RH) are shown in columns 1-3 and the secondary factors of climate seasonality (CS) and tropical storm frequency (TSF) are shown in columns 4 and 5. Highly suitable areas are indicated by a ✓, a light shading indicates some deviation from the criterion, and a dark shading denotes largely unsuitable conditions for the specific parameters.

Parameter	T (°C)	P (mm/yr)	RH (%)	CS	TSF
Criteria	>27	<2000 >6000	>60 avg>75	<100 mm/mo	high freq
Isthmus of Panama - Atlantic side	✓	✓	✓	✓	✓
- Pacific side	✓	✓	✓	4 mo dry	✓
Isthmus of Kra, Malaysia	✓	✓	✓	✓	✓
SE Costa Rica	T=19	1,780	✓	✓	✓
North Honduras	T=26	✓	no data	✓	✓
Belize (All Pine -Mullins River)	T=26	1,805	✓	✓	✓
Puerto Rico	T=26	1,525	✓	✓	
SW New Britain/New Ireland	✓	>1,140/mo	✓	✓	✓
SW New Guinea Lowlands	✓	✓	✓	✓	✓
East Indies (East-Central Java & SE Borneo)	✓	✓	✓	✓	✓
Philippines (NW Mindanao & SW Luzon)	✓	✓	✓	<55/mo	
NE Australia (Cape York Peninsula)	✓	✓	✓	dry season	✓
Hawaii (portions of Hawaii, Oahu, Maui, & Kauai)	T=22	✓	✓	✓	✓
Coastal French Guyana & NE Brazil (Belem area)	✓	✓	✓		✓
NW Colombia (Andagoya)	✓	7,140	✓	✓	✓
Coastal Thailand	✓	1,400	✓	✓	✓
Western Fiji	✓	✓	✓	✓	✓

first filter of potentially promising tropical locations. This evaluation is presented in Table 2 and Figure 2 shows the general areas of the world where these conditions are found. The most desirable group of sites from these regions based only on climate indicators are as follows:

- North Honduras (Ironia-Tela)
- Isthmus of Panama
- Coastal French Guyana/Brazil (Belem area)
- Western Fiji
- New Britain/New Ireland
- SW New Guinea Lowlands
- East Indies (East-Central Java & SE Borneo)
- Isthmus of Kra, Malaysia (not local to Prachucap Khiri Kan)

III.4. Physical Requirements

III.4.A. Physical Characteristics

Although recognized that the landscape is a complex physical system interrelated to geology tectonics, climate, and vegetation (e.g. Ritter et al., 1995; Birkland, 1984; Bloom, 1978), for the purposes of this exercise it is considered that the primary factors having a direct effect on the physical setting are the topographic characteristics: elevation, relief, and slope. In large part, these factors are controlled by forces external to the landscape. The principal external driving force, tectonics, dictates the geologic framework of a region (Morres and Twiss, 1995) and can shape and reshape the landscape with the aid of climate and biologic factors.

The ideal tropical test facility setting will have an approximate elevation range of 0 to 1500 m, local relief up to 150 m, and slope of 0 to 60 percent. These criteria should allow the inclusion of areas of low-relief coastal plain and wetlands with rivers and flood plains, as well as rolling hills of moderate relief, grading to steep high-relief uplands. A variety of river and stream channel morphologies will be represented, including steeply sloping mountain streams, braided channels of moderate gradient, and low-gradient meandering rivers.

Secondary physical characteristics that are assumed to exist as a function of the topographic and climatologic factors (discussed elsewhere) defined in this study include, but are not limited to, geomorphology, soils, and hydrology. In general, bedrock geology and structure is most important with respect to landform distribution and landscape evolution (Ritter et al., 1995; Bloom, 1978). In addition, rock type influences its susceptibility to weathering. For example, intrusive rock tends to weather at an accelerated rate relative to finer-grained volcanic, volcaniclastic, and clastic sedimentary rocks (Birkland, 1984; Soil Survey Staff, 1975). Because of the deep weathering profiles that are typical of most humid tropical landscapes, the influence of rock type on geomorphic expression is generally subdued by the thick saprolite and soil cover overlying bedrock. Important and undesirable exceptions to this are limestone regions with thin soils, little saprolite, and karst development. Major soil orders that are likely to be present in the ideal site include Oxisols, Ultisols, Inceptisols, as well as Entisols in some local areas, (e.g., young fluvial terraces, uplifted coastal environments, some hillslope components (Soil Survey Staff, 1975).

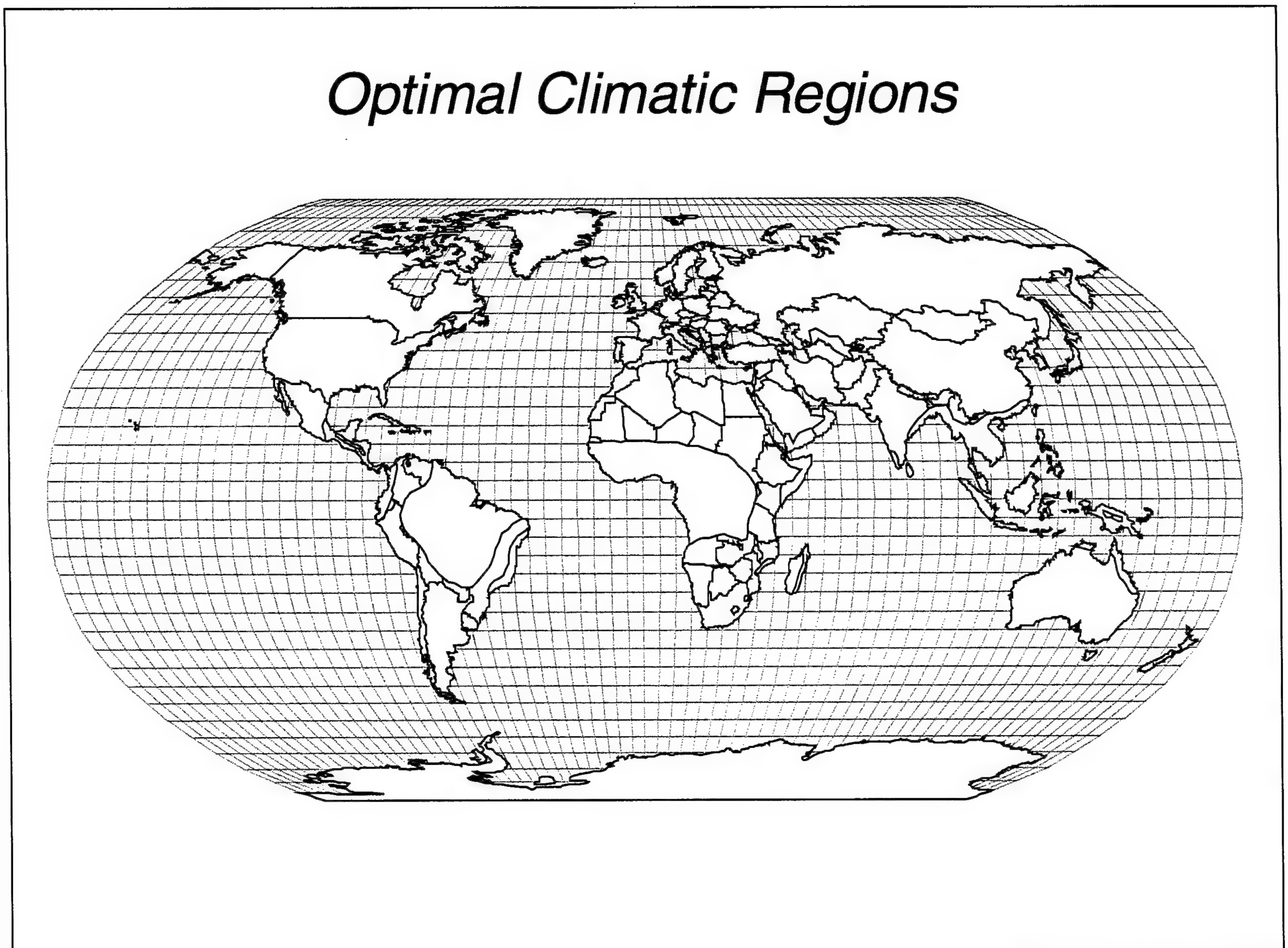

Figure 2. Locations of Tropical Environments based on Climate

III.4.B. Tectonic Factors

Tectonic factors are the fundamental control on the spatial distribution of rock types, which influence the topography, and geomorphology of a region (Ritter et al., 1995), and ultimately, on the suitability of physical settings for tropical test facilities. Physiographic regions and regional landscapes can be characterized according to the relative degree of tectonic activity, which provides a generalized ranking of most to least suitable locations. Variability within the tectonic framework and relative activity can result in a variety of landscapes within a given plate tectonic setting (e.g. Wells et al., 1988; Gardner et al., 1992).

Plate boundaries considered in this study included convergent boundaries in ocean-continental and ocean-ocean settings, passive margins and plate interiors, transform boundaries and intraoceanic volcanic islands. Within the convergent boundary settings, the fore-arc setting and back-arc settings are distinguished.

In general, convergent plate margins are potentially suitable locations because they typically have great relief, have large elevational change across short distances and have a variety of landscapes present in a compact area, and they are bordered on one side by an ocean. Thus a variety of rock types, slope conditions, microclimates, soils, and biota characterize these regions and make them attractive sites for tropical testing.

Regions of intermediate suitability include passive margins and plate interiors, transform boundaries, and intraoceanic volcanic islands. In most cases, the relief and topographic variability of passive margins and plate interiors, and transform boundaries may not be as great as that found along active plate margins, but may provide the basic requirements for a tropical test facility. Volcanic islands outside of island arc settings may have suitable relief and slope, but soil variability may be less apparent. Finally, least suitable sites include low-relief setting such as atolls and islands on carbonate platforms (i.e., Bahamas)

III.4.C. Geologic Hazards

Geologic hazards must be taken into consideration in site selection. In convergent plate boundary settings, geologic hazards may play dominant roles in shaping the landscape and may impact infrastructure and operations. For example, volcanic eruptions have threatened military installations and personnel (i.e. Mount Pinatubo, Philippines forced the evacuation and closure of Clarke Air Force Base) and earthquakes have damaged facilities (e.g. Guam, 1993; Loma Prieta, 1989). In earthquake prone areas, site location and design should be evaluated for ground shaking-related phenomena (potential for liquefaction, rockfalls, landslides, etc.) and surface-fault rupture, with those areas recognized as being susceptible to significant hazard zoned for appropriate uses. Areas prone to landslide activity may have localized areas of high hazard that should be evaluated, but in general such areas should be acceptable. Areas with potential for significant storm surge and tsunami hazard should be avoided.

III.4.D. Summary of Physical Setting

A simplified set of parameters was developed to describe the physiographic, tectonic, and geological character of the candidate areas generated from the climate analysis described in Section II. The 17 candidate locations identified from the climate analysis are evaluated against these physical characteristics in Table 3. All sites listed have acceptable elevation, relief, slope, and soils. Belize is an exception and soil conditions may not be ideal.

III.4.E. Hydrologic Setting

The hydrologic cycle provides a basic framework for analyzing the exchange (inputs, storage, and outputs) of water and moisture between the atmosphere, surface (to include ocean bodies, lakes, and rivers), and subsurface in the tropics. The humid tropic regime is characterized by an abundance of precipitation. Total annual rainfall amounts and their monthly distributions are critical to defining the hydrologic regime in tropical environments and have been discussed in detail in the climate section. Several climatic and hydrometerological classification schemes have been developed to quantify rainfall regimes in the tropics. The desirable tropical test environment is characterized by total annual rainfall amounts in excess of 2,000 mm (80 inches). The environment should be constantly moist or experience only a short-duration dry season. In the latter case, no less than 100 mm (4 inches) of precipitation should occur during any single month of the dry season. Overall, the rainfall regime must be adequate to sustain a tropical rain forest environment. Figure 3 depicts the areas of the world that meet the general criteria for hydrologic input.

The generation of overland flow and significant near-surface and sub-surface (i.e. macropore) throughflows are key components of the tropical hydrologic system. These sources of water and their means of conveyance directly determine the patterns of stream development and morphology. Stream channels and their associated networks are controlled by a combination of physiographic variables, such as bedrock type, underlying geologic structure, soil hydraulic characteristics, slope, and vegetative cover. Larger water courses are typically perennial, while smaller channel systems may be more sensitive to surface and sub-surface inputs and fluxes. In general, humid tropical fluvial systems can be defined by well-developed channel systems, perennial flows, variable widths and depths, heavily vegetated banks, a broad size-range of bed materials and range of dissolved and suspended loads. In areas influenced by tectonic processes, channel morphology may vary dramatically along a rivers long profile due to horizontal and vertical bedrock controls.

The groundwater component of the hydrologic system is not considered critical to the testing environment. Typically, deeply weathered soil and saprolite profiles in tropic environments overlie bedrock with significant depths (10's of meters) to bedrock, precluding interference with subsurface testing. Exceptions to this exist in areas characterized by limestone formations where high rainfall and chemical weathering may cause dissolution of the sedimentary formations, resulting in irregular karst topography (sinkholes, caves, underground streams). As noted earlier, karst terrain should be avoided in selecting a preferred testing location.

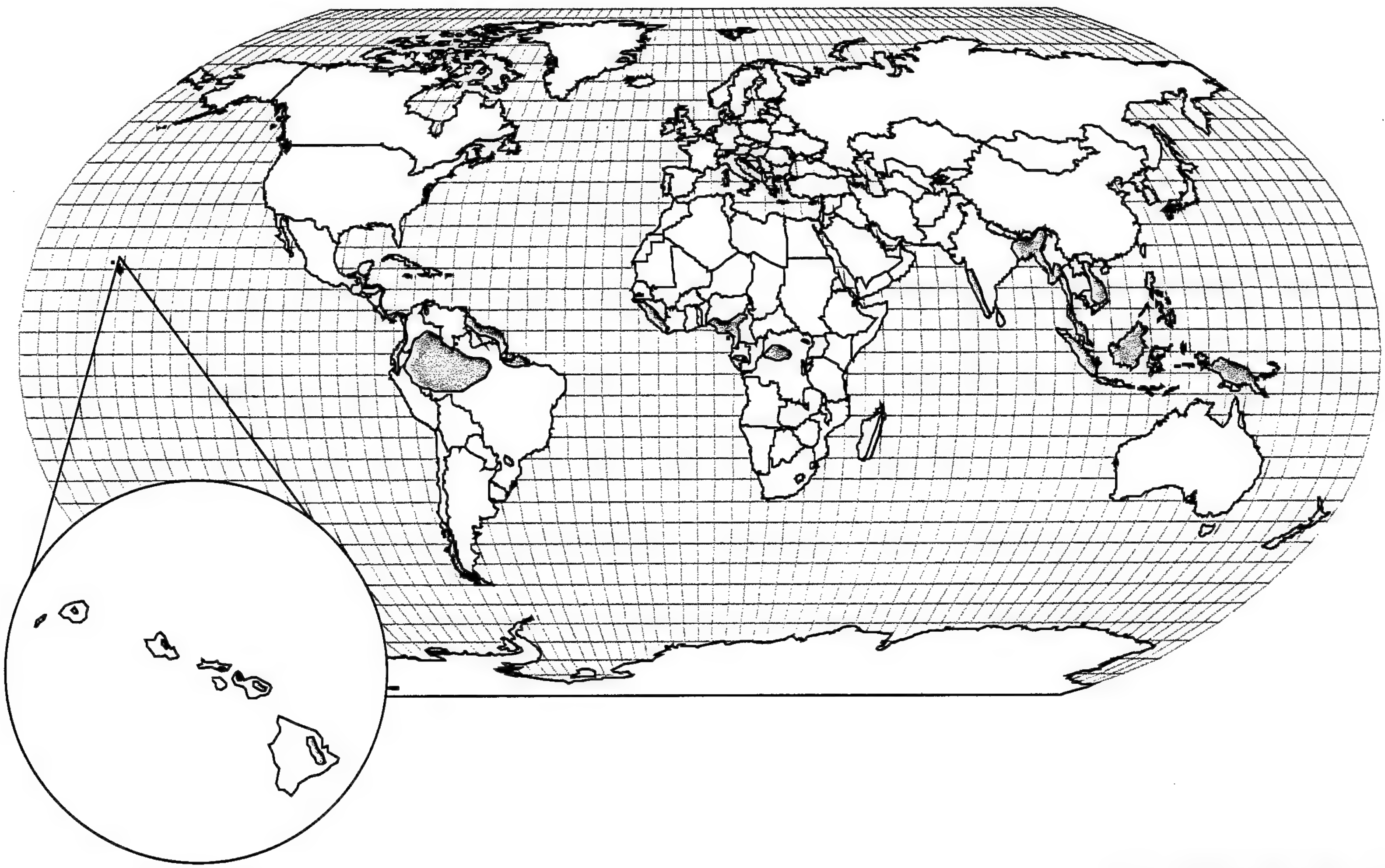

Figure 3. Locations with Precipitation Levels acceptable for Tropical Testing

Table 3. Physiographic and geologic factors considered in rating potential locations for tropic testing (Cf = convergent plate, forearc; Cb= convergent plate, backarc; I = passive margin and/or plate interior; T= transform plate boundaries; Ov= oceanic volcanic islands; P= passive plate; ✓ = presence of suitable conditions).

Potential Locations	Elevation	Relief	Slope	Soils	Margin
Isthmus of Panama	✓	✓	✓	✓	Cb/P
Isthmus of Kra, Malaysia	✓	✓	✓	✓	I
SE Costa Rica (Limon-Cahuita)	✓	✓	✓	✓	Cf, Cb
North Honduras (Ironia-Tela)	✓	✓	✓	✓	I
Belize (All Pines-Mullins River)	✓	✓	✓	-	I
Puerto Rico	✓	✓	✓	✓	Cf, Cb
SW New Britain/ New Ireland	✓	✓	✓	✓	Cf,Cb
SW New Guinea Lowlands	✓	✓	✓	✓	Cf
East Indies (East-Central Java & SE Borneo)	✓	✓	✓	✓	I
Philippines (NW Mindanao; SW Luzon)	✓	✓	✓	✓	Cb,P
NE Australia (Cape York Peninsula)	✓	✓	✓	✓	I
Hawaii (Portions of Oahu and Kauai)	✓	✓	✓	✓	Ov
Coastal French Guyana/NE Brazil	✓	✓	✓	✓	P
NW Colombia (Andagoya)	✓	✓	✓	✓	Cb
Coastal Thailand (excluding Bangkok area)	✓	✓	✓	✓	I
Western Fiji	✓	✓	✓	✓	Ov

Functionally, the operation of fluvial systems in tropical environments is similar to other humid environments. Therefore, there are no fluvial features which are unique to the tropical environment. However, the selected tropical test center location should contain both small (1-2 m wide) and larger (10-20m wide) watercourses for vehicle mobility, bridging and stream-crossing operational testing. It is preferable that these watercourses be more stable and meandering than incising, since the latter more active channels generally produce gradients, bank conditions and channel bed characteristics that are undesirable for testing purposes. There should be at least one large (10-20 meter wide) river with perennial flows. Flow depths should be adequate to allow swim testing and fording of wheeled and tracked vehicles.

The primary concern for water quality is attaining unrestricted human use of the surface water systems. It is assumed that prolonged human contact may be needed for field testing of military equipment, particularly personal equipment. Key water quality indicators are dissolved oxygen, total dissolved solids, pH, turbidity and the presence of micro-organisms. Certain biological contaminants are direct threat concerns in many natural waters in the tropical environment. TB MED 575 (1993) lists the following organisms as the most common biological contaminants in natural waters: *Leptospira interrogan, Giardiasis lamblia, naegleria fowleri, and Schistosomi mansoni.* The later two organisms are vectored through natural processes and are common in warm waters, including the tropics. Table 4 is a compilation of suggested water quality standards based on US EPA and US Army published criteria. The primary concern is with the microorganisms because they have directly been correlated to the incidence of disease from water contact. The organisms listed in Table 4 are indicator organisms whose presence demonstrates that environmental factors exist which can sustain the hazardous organisms listed above. The remaining parameters are simply suggestive of overall acceptable water quality and need not be rigorously applied. These data will be available only on a site specific basis and therefore cannot be incorporated into the screening criteria. They are included here as a reference for further siting work.

Table 4. Recommended water quality criteria (mg/L = milligrams per liter, mL = milliliter)

Parameter	Criteria	Primary Impact
PH	6.5 to 8	eye irritation and minor health
Dissolved Oxygen	>4 mg/L	indicator of pollution
Water Velocity	<1.5 m/sec	safety for in-stream activities
Total Dissolved Solids	fresh water: <1,000 mg/L brackish water: <5,000 mg/L sea water = 35,000 mg/L	determines aquatic species that can be supported
Microorganisms	Coliforms < 4/mL Enterococci < 1/ mL (salt) Enterococci < 1/ mL (fresh) *Escherichia coli* < 1.3/mL	human health risk

III.5. Biological Requirements

III.5.A. Overview

Given the specific climatic, topographic and geographic constraints listed above, the major biological considerations for a tropical testing site are the vegetation characteristics and presence of a diverse community of above- and below-ground organisms. In the past, military interest in tropical vegetation was primarily its structure and distribution in both horizontal and vertical dimensions as challenges to vision, mobility, and performance of personnel and equipment. For other organisms, especially microbes and fungi, the concerns focus primarily on the detabolic processes that foul materiel and interfere with equipment dnd systems under test. Military testing at present and in the future requires much greater detail and understanding of the structure, function, and interrelationships of species in complex tropical ecosystems.

III.5.B Vegetation

Vegetation criteria in this discussion emphasize the physical characteristics of the vegetation community more than the ecofloristic description of tropical ecosystems required for testing. Vegetation structure requirements for tropical testing range from relatively open areas with low biomass to densely stocked stands of herbaceous plants and completely closed canopy, high biomass, multistrata relatively closed canopy forest. A moderate seasonal change in canopy density may be advantageous for visibility and litterfall effects testing, as well as in the context of a predictable annual variability. Forest types suitable for year- round tropical testing include tropical moist forest as well as montane, low montane, and premontane forests. If the requirement for year-around testing is relaxed, then many vegetation types in areas other than tropical regions would meet the minimum criteria for some testing (e.g. "line-of-sight") during seasons with hot, wet conditions within the climatic requirements for tropical testing. However, other testing such as long term materiel exposure testing mandate the necessity of truly complex, diverse and mature tropical environments. Figure 4 shows the spatial distribution of tropical vegetation throughout the world.

The most crucial vegetation structure type for tropical testing purposes is the closed canopy forest, with evergreen or a mix that includes semideciduous species. Access to areas with a dense understory (i.e. visibility of standard target < 10 m) is important for testing and training purposes. For example, ground visibility ranged from 4.4 to 16.2m in earlier studies on the TTC Gamboa test area with a standard target of 1.5m (Rula, 1979). Of secondary importance are grassland, savanna, or shrubland cover types, all which are accessible to the current TTC facility in Panama. Regardless of cover type, issues of ecological importance such as diversity of species present and forest successional state (i.e. "primary" forest versus "secondary", disturbed or regrowth forest), are emerging as subject areas of greater interest as military sensor and survivability systems grow in sophistication. Interpreting the composition and condition of the canopy may reveal intelligence about human activities below its cover. Knowledge about species physiochemistry and life histories may help military actions to avoid biological hazards, correct for communication interference, and survive off the land. For all of the above, secondary forest, probably the most consistently

Optimal Vegetation Regions

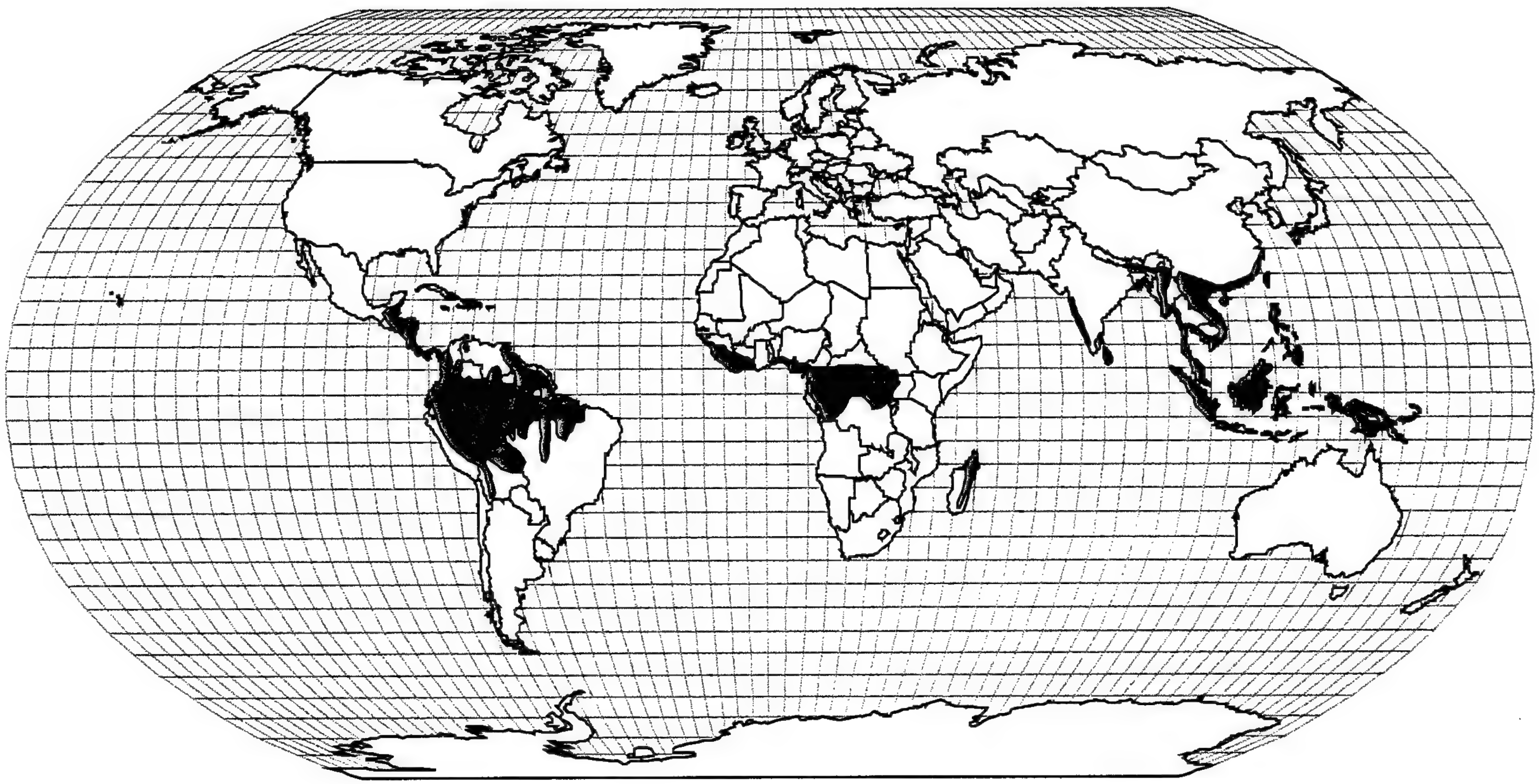

Figure 4. World-wide distribution of Tropical Vegetation

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encountered type in the tropics due to widespread anthropogenic disturbance, is entirely appropriate for testing use once minimal requirements are met. Secondary forests on the order of 25 years old would meet these requirements and_deliver the kind of tropical forest ecosystems that would attenuate sound, challenge electromagnetic sensors, and emit aromatic compounds that mimic biochemical agents. Older growth forests provide a different suite of conditions for testing activities related to mobility and visibility since canopy closure greatly reduces understory vegetation development.

Forests suitable for tropical testing generally have a stem size class distribution with the bulk of stems <10 cm in diameter [70 - 95%], but with a small but significant representation of stems >20 cm diameter [1 - 10%] and a basal area of 20 to over 70 m^2 ha^{-1}. A review of the literature for tropical sites showed forest structure to be composed of an average of 85% of stems in the 1-9 cm diameter class, 11.5% 10-19cm, and with less than 2% in the 20-29 cm class. Larger size classes, 39-39 cm diameter and >40cm diameter, account for <1% each of the stem size distribution (Brunig, 1983). The presence of a significant number of stems in the >10cm class is important for vehicle trafficability. Other important characteristics are the distribution of both leaf area and stems, both horizontally and vertically. However, given the climatic characteristics for testing, most forested areas will have suitable characteristics once the minimal frequency size class distribution is met. In a secondary forest situation, time since disturbance and intensity of disturbance, as well as local site conditions, will affect suitability for testing.

III.5.C. Functional Classes of Organisms

Above and below-ground organisms are important for the selection of appropriate sites. Above-ground flora and fauna are important to the testing effort; they present realistic challenges to personnel and equipment under test and are one feature of the natural environment that cannot be easily duplicated in test chambers or computer simulations. Animals and insects can damage equipment through direct contact (chewing, eating, moving, nesting, burrowing) or a rain of debris and waste, as well as through colonization and consumption by soil and canopy organisms. Injurious plants and wildlife can impair soldier performance. The individual species of fauna and flora are not critical, assuming that similar ecological niches will be filled as long as suitable climatic and vegetation characteristics are met.

For the purposes of tropical testing, the diversity of the lower canopy, forest floor, and below-ground decomposer community should be as diverse as possible to offer the widest range of challenge to materials under test. To insure maximum vegetative diversity, a continental site would be preferred over island sites or large islands would be preferred over small islands. It is important that a broad range of decomposers (insects, fungi, microbes) be present for materials biodeterioration testing. In the tropics, termites are an important group of organisms in the physical and chemical breakdown of plant material. Their activity will affect cellulose-containing test materials and their nests may also be placed on test items. Another issue of importance for testing is the large quantity of canopy litter input to the tropical system. Canopy litter spans materials as small as waste or fragments of plants and other organisms, to flowers, fruit and woody debris. Litter fall is significant in all tropical systems, with a range of approximately 0.4 - 2.3 $kg/m^2/yr$, with an average of 0.96

$kg/m^2/yr$ (Jordan, 1983). Panama sites have litter fall rates in excess of 1.0 $kg/m^2/yr$. Smaller litter components can cover test materials along with associated microflora and fauna in situ on fallen materials, whereas larger woody pieces and fruit may cause physical damage due to mass.

III.5.D. Anthopogenic and Natural Hazards Impacts

Vegetation related issues that would negatively influence the suitability of a site for testing would include extensive deforestation and other disturbance regimes that reduce the density and biomass of tree and understory or reduce the size of intact stands of vegetation suitable for testing. Fires could artificially reduce understory closure, increasing visibility and deforestation. Clearing or selective logging could completely remove large components of the tree cover, damaging the canopy and understory. Location in an area of frequent hurricanes or other severe storms would also compromise infrastructure and forest integrity. Selection and access to an area of approximately 10 km^2 or more would reduce the impact of local natural or anthropogenic disturbance and allow continuous access to suitable areas.

V. SUMMARY ANALYSIS

The requisite characteristics of the environment for an ideal tropic test center are derived from a complex interaction of the several key factors. Climate is the defining characteristic of tropical regions, whereas physiographic and geologic factors are the most important modifiers of climate, and the biologic manifestations (land cover/vegetation type) are a direct function of the combination of climate, physiography, and geology in a given region. However, because of complex feedback mechanisms, land cover also influences local/regional climate. Therefore, in the search for an ideal future tropic test center, this ranking of factors (climate, physiographic/geologic, and biologic) provides a simplified means for site evaluation. A conceptual depiction of constructing the ideal tropical test facility is presented in Figure 5 and the criteria identified as defining the ideal tropical test environment from a scientific basis are summarized in Table 5.

The ideal climate for a tropical test facility would lie in the wet tropical regime, to provide extremes of high humidity in a very high rainfall and high, constant temperature environment. As such, the area encompassing the site should have annual precipitation in excess of 2 meters (80 inches), monthly-averaged minimum temperature and relative humidities in excess of 18-20^{o}C and 60%, and mean monthly temperatures and humidities of at least 25^{o}C and 75% respectively. Rainfall in any single month will not fall below than 100mm, nor exceed 6,000 mm/yr. These precipitation requirements address a desire for minimal seasonal variability (preference for no absolute dry season). Regions experiencing tropical cyclone (hurricane or typhoon) activity should be avoided, unless all other physical factors indicate the most optimal location. Temperature ranges for these climate regimes exist over large regions of the tropics, especially those confined to a near-equatorial belt ($\pm 7^{o}$ latitude) or more poleward regions in the tropical western Pacific. The wet tropics are typically confined to western ocean basins, collocated with the regions of highest sea surface temperatures and temperature gradients. In these regions, high relative humidities and precipitation are the norm, with local topography and prevailing winds modulating the broad-scale climate structure.

Table 5. Criteria for an Ideal Tropical Test Area

I. Climate:

Precipitation: → 2-6 meters (m) per year
→ > 0.1 m in driest month

Temperature (degrees C): → 18 minimum
→ 27-40 average daily

Relative Humidity (%): → mean = 75
→ range = 75 to 90

II. Physical Setting:

Relief: → elevation = Sea level to 1,500 m
→ site relief = 150 m minimum
→ slope = 0 to 60 %
→ coastal location with lowlands

Surface water: → minimum = 60
→ perennial small (1-2 m) to medium (up to 20m) width streams, with nominal velocities (<20m/s)

Soils: → oxisols, ultisols, inceptisols
→ minimum depth in the range of 10 m

Tectonic Factors:
→ low hazard area

III. Biological Considerations:

Secondary tropical rainforest
Undisturbed growth for 25 years minimum
Established understory growth
Heavy canopy
Diverse fauna and decomposer populations
Grasslands and savannas

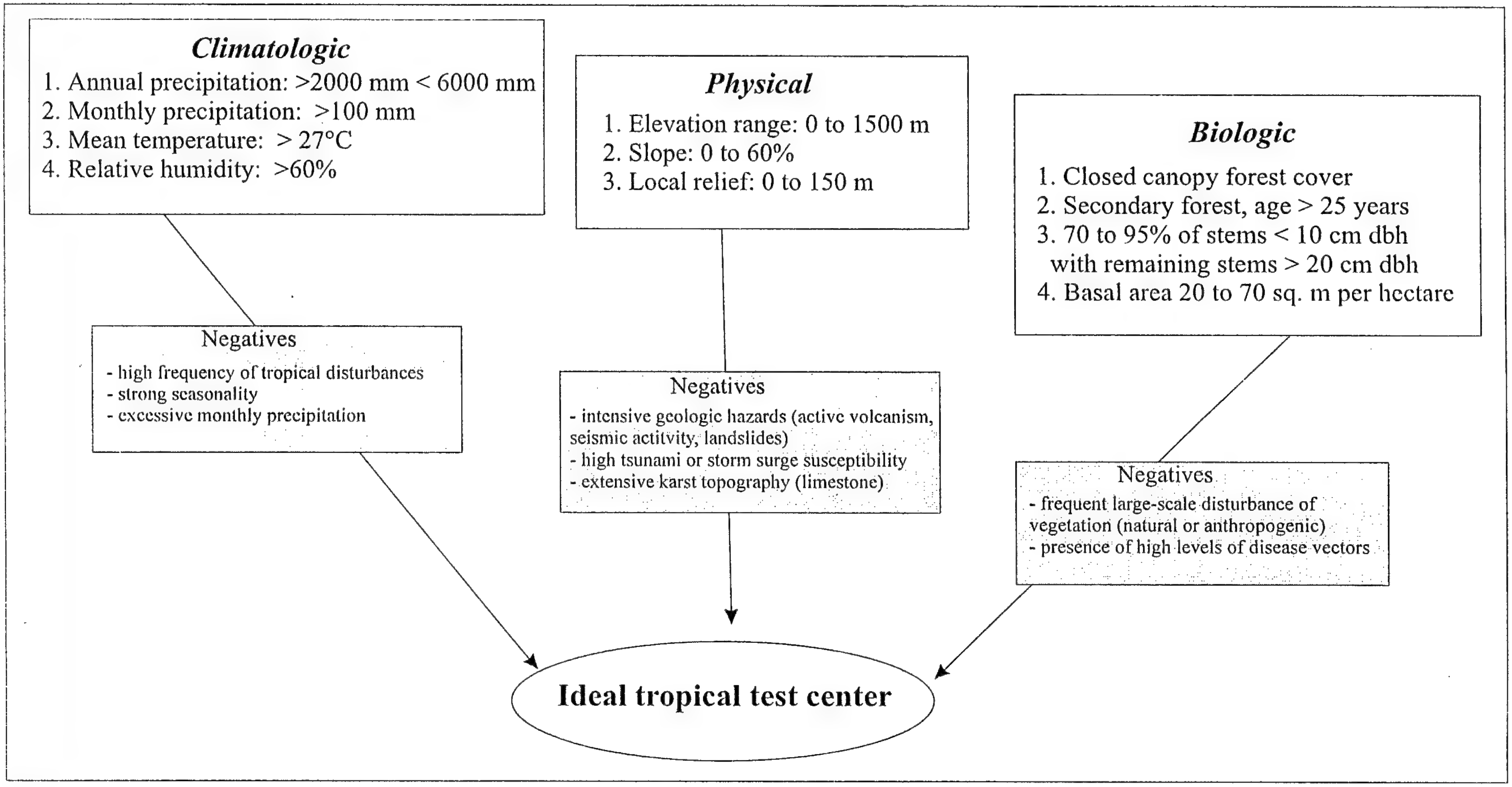

Figure 5 Conceptual model showing principal environmental factors (and significant negative influences for each) used to define the ideal tropical test center. [dbh, diameter at breast height; m, meters; mm, millimeters; C, Celsius]

The ideal physical environment will be found at a coastal plate boundary tectonic setting that offers a combination of beaches, coastal landforms, and interior lowlands. It should also be a margin that is not highly active tectonically. There should also be an absence of karst topography. The soil type and structure should follow with the climate and primary physical criteria.

The biological criteria are dependent on the climate and the geology, absent man's adverse impacts on the area. It was estimated that 25 years of secondary growth in a tropical climate would be sufficient to restore a tropical rainforest to a stage adequate to consider the biological setting ideal. Further, a continental or large island setting is preferred to provide the diversity of species characteristic of an ideal and healthy environment. This is necessary to allow for continued regeneration of an area being stressed by testing activities.

Based on a composite of the criteria from climate, physical setting and biota, Figure 6 depicts the areas of the world which meet the defining criteria. Also shown in Figure 6 are the specific regions that offer both full conformity (*i.e.* optimal) and partial (i.e. acceptable with reservations or limitations) to the criteria. Note, because of the exclusion established in the panel charter (Figure 1), no sites are listed in Africa even though there are areas on that continent that fulfill the criteria.

V. SPECIAL CONSIDERATIONS

To this point, site selection has focused only on the physical, climatological, and biological considerations. There are other important, if not critical, elements in the selection process that are beyond the scope of this study, but must be presented along with our findings. First is the issue of institutional support. Testing of military equipment will require the cooperation of military units and availability of troops for both operational and human factors testing. As has been previously discussed, operability is one of the areas of interest in tropical testing. The question is not whether the equipment can operate in a tropical environment, but if a soldier can complete his or her mission utilizing the equipment under the harsh conditions of a tropical environment. An important special case for soldier availability is access to weapons firing ranges. Currently, TTC relies extensively on the USARSO resources for support and specifically for small arms and artillery firing ranges. The absence of similar support capability would limit the capability of any test facility.

The second practical concern is the requirement for overall infrastructure support for a future test facility. By their nature, most of the suitable localities for tropical testing identified in this study are remote areas, typically lacking basic transportation, office facilities, and other required support infrastructure that are normally assumed to be available. The cost of buildings and other facilities being installed in a remote location will be high. An important element of this support is the availability of a trained professional civilian staff required to accomplish the testing and analysis activities. Over time, the TTC has developed a well-trained staff of experts in tropical testing, most of whom are Panamanian. Panama is quite unique in the context of being an accessible location that offers both modern infrastructure and a well-educated professional labor pool in close proximity to a suitable tropical environment. Many of the alternative areas identified in this study either lack accessibility, infrastructure, or a local labor base that could support testing. One important

conclusion arising from this study is that isolated jungle locations are going to be very difficult places in which to establish and operate the kind of tropic test facility required by the Army of the 21st century.

A third consideration for the establishment of a new TTC involves issues of land use and natural resource sustainability. The footprint of the TTC on the landscape must be minimal to ensure long-term sustainability of the desired tropical environment (physical and biological components). Human disturbance of the test environment from off-site pollution sources (air, water, and soil transport) may alter critical test measurements. Encroachment from indigenous populations, and urbanization are potentially problematic. From this perspective, a degree of remoteness countered by accessibility and maintenance costs, is desirable. Conversely, the level of impact of testing on the surrounding environment must be understood and minimized. While many of the testing methodologies, such as materials exposure testing, are benign, other tests may result in trans-boundary impacts such as noise, air and water pollution, and habitat destruction. This is particularly the case with weapons, explosives, and vehicle testing. Here again, a degree of remoteness is desirable. It is also unlikely that any new tropical test facility would be established within environmentally designated protection areas, since some degree of impact must be anticipated.

VI. DECISION TREE

A technical description of the ideal tropical test environment has been developed and obvious non-technical considerations that are certain to impact the final site selection have been discussed. The next logical step is to develop a hierarchical method to conduct site evaluations. Below, parameters describing climate, physical, and biological have been ordered into a site evaluation decision tree. The decision tree structure is weighted from highest to lowest, with details of ranges noted in Table 5:

A. Essential tropical parameters include:

1. Diurnal and annual temperature (mean and ranges)
2. Annual and monthly precipitation level (mean and ranges)
3. Relative humidity
4. Physiography (relief, slope, elevation range)
5. Biotic communities (vegetation structure)

B. Characteristics deemed highly desirable, but not critical, include:

1. Minimal effects of tropical cyclone (hurricane or typhoon) activity
2. Seasonality (minimal dry season preferred)
3. Range of vegetation types (forest, swamp, grassland)
4. Range of landscape types (sea coast, coastal wetland, coastal plain, upland)
5. Well-developed and variable soil profiles (Oxisols, Ultisols, Inceptisols, Entisols)
6. Range of stream sizes and flow regimes

C. Screening criteria resulting in the elimination of otherwise acceptable locations include:

1. Intensive geologic hazards (active volcanism, seismic activity, landslides)
2. High tsunami/storm surge susceptibility
3. Presence of extensive karst topography (limestone)
4. Frequent or large-scale disturbance of vegetation (natural and/or anthropogenic)
5. Presence of high levels of disease vectors
6. Excessive monthly or annual precipitation
7. Impacts of farming, industry or urbanization
8. Land use restrictions

VII. CONCLUSIONS

This study has achieved two major results:

(i) The ideal environmental setting for a tropical testing has been defined (Figure 5), and

(ii) Regions of world have been identified that best fulfill the ideal tropical test center model (Figure 6 and Table 6).

The ideal tropical test center is based on a vision of the future needs of the Army and the DoD to challenge military equipment and soldier-equipment systems with the environmental factors that best characterize the wet tropics. The model was constructed from the fundamental properties of climate, terrain, and biota to allow for its general application to evaluating site alternatives. This approach was taken by the panel with the understanding that practical considerations for establishing a tropical test facility outside of Panama may obviate many sites that are preferred on the basis of the technical considerations defined by the panel. This led to the construction of a decision tree as an aid in evaluating specific site alternatives.

Table 5 summarizes the parameters that define the ideal tropical test environment in terms of climatological, physical, and biological parameters. Climate and geophysical setting are clearly the dominant factors that control all other variables in defining the ideal test setting. For example, biological properties are absolutely critical to the test site, but the optimum biological setting is achieved only in those areas that possess the requisite climate and soils. This does assume the area is absent of anthropogenic disturbance for the previous 25 years. From the panel analysis of these factors, the regions of the world that meet these criteria are shown in Figure 6 and specific locations suitable for the Army tropical test mission are rank ordered in Table 6.

An important characteristic of this study is that the panel began by developing a set of suitability criteria on the basis of desirable environmental factors and then used these to identify specific areas of the world suitable for the Army tropical test mission. This approach differentiates this study from others that simply considered the relocation of the Army Tropic Test Center from its present site

Optimal Test Center Locations

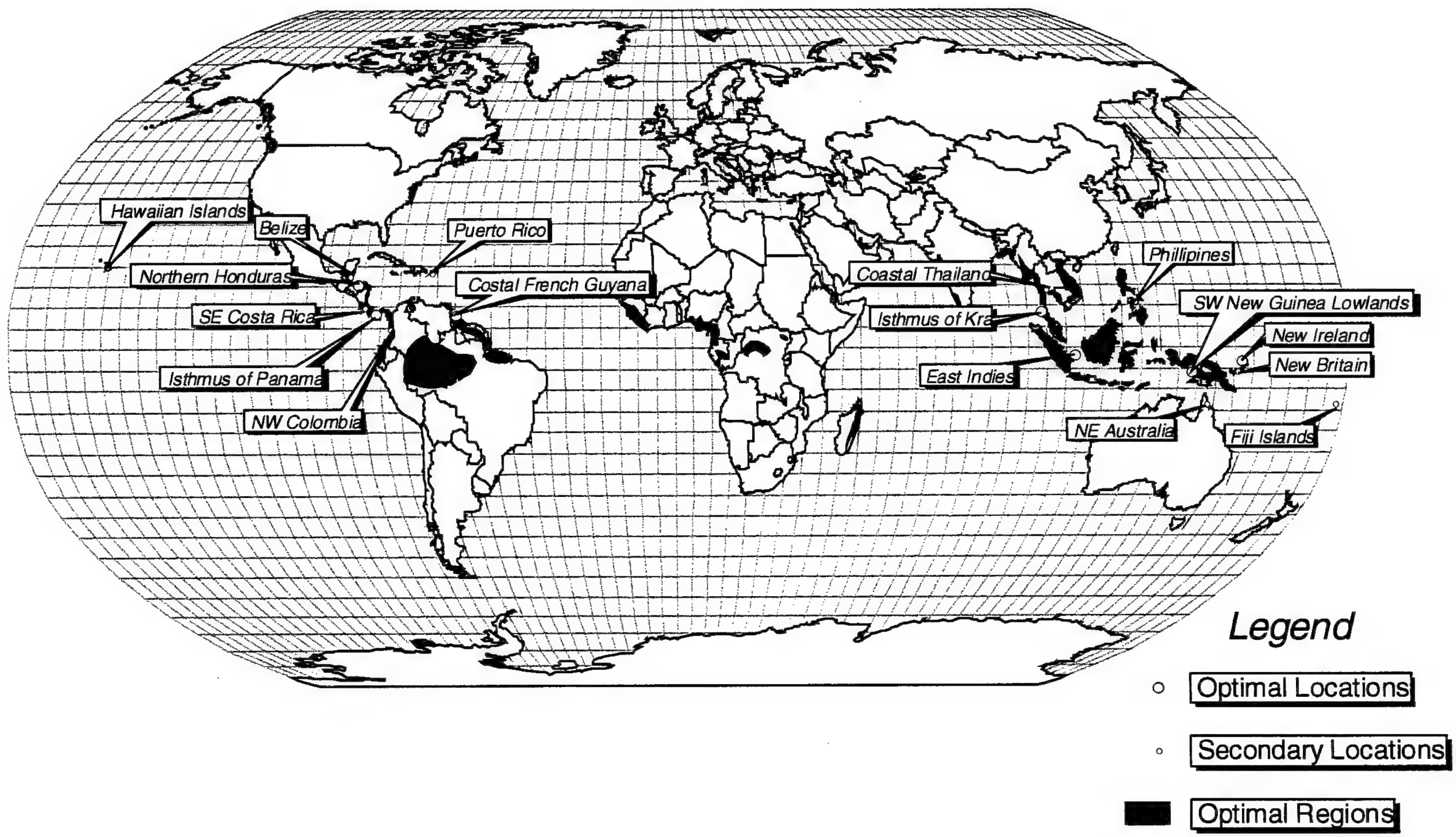

Figure 6. Optimal Tropical Test Center Locations

Geography & Environmental Engineering Department
United States Military Academy

Table 6. Comprehensive ranking of suitability based on major climate, physiographic, and biological factors with the locations within each group ordered in terms of proximity to the US.

GROUP 1 (meet all criteria)			
1. North Honduras (Ironia-Tela)	Y	Y	Y
2. Isthmus of Panama	Y	Y	Y
3. Coastal French Guyana/NE Brazil (Belam)	Y	Y	Y
4. SW New Guinea Lowlands	Y	Y	Y
5. East Indies (East-Central Java & SE Borneo)	Y	Y	Y
6. Isthmus of Kra, Malaysia	Y	Y	Y
GROUP 2 (meet most, but not all, criteria)			
7. Puerto Rico	N	Y	Y
8. Belize (All Pines-Mullins River)	N	N	Y
9. SE Costa Rica (Limon-Cahuita)	N	Y	Y
10. NW Colombia (Peninsula de Guajira)	N	Y	Y
11. Hawaiian Islands*	N	Y	Y
12. Fiji Islands*	N	Y	Y
13. Philippines (NW Mindanao & SW Luzon	N	Y	Y
14. NE Australia (cape York Peninsula)	N	Y	Y
15. SW New Britain & New Ireland	N	Y	Y
16. Coastal Thailand (excluding Bangkok region)	N	Y	Y

* Parts of the Hawaiian Islands on Hawaii, Oahu, Maui, and Kauai as well as Western Fiji have the required climate conditions, but those conditions meeting the precipitation criteria tend not to meet the temperature criteria, and vice versa.

The first set of criteria (A1-A5) are absolute; the second six criteria (B1-B6) are highly desirable. No filtering on the requirement for persistent onshore coastal flow has been performed. Data to address this issue are not readily available, however, this characteristic would most likely be met at open coastal locations. Table 6, which is based criteria given above and the results shown in Figures 3 and 4, indicates the most suitable (Group 1) and acceptable regions (Group 2) for tropical testing.

within the canal zone region of Panama. Therefore, the fact that Panama was observed in this study to be a strong fit to the idealized tropical test facility of the future is important because it verifies the use of data from the numerous analog studies done which have compared other sites around the world with Panama. Some caution is necessary in examining these earlier studies because they are based solely climate parameters and these parameters do not completely define the ideal tropical test environment. However, the conclusions drawn in these reports that no site in the continental US (Williamson et al., 1987a), Puerto Rico (Brownley et al., 1985), or the Hawaiian Islands (Brownley et al., 1985) contains the combination of climate, terrain, and vegetation characteristics required for Army testing in a hot-humid tropical environment, are fully validated by this study. Similarly, the observation that locations in Hawaii and Puerto Rico that were capable of meeting some of the requirements, but none provided the full range of environmental conditions manifest within the present TTC facility in Panama was also confirmed by the present study.

The overall conclusion from this panel study that both the scientific data and practical considerations support Panama as an optimum site for the testing of Army materiel, systems, and human performance has direct management implications. Within Panama, the Atlantic side of the isthmus at Ft Sherman provides the climate conditions, the varied physiographic settings, and the biological communities that define an idea tropical test area. Therefore, negotiating with the government of Panama to continue the Army tropical test mission in Panama, within the terms and conditions of the Cater-Torrijos Treaty when implemented at the end of 1999, is seen to be a more attractive option for the Army than all other possibilities developed by the study panel during its discussions and deliberations.

In the charter for this study (Figure 1, Paragraph I.2, and Appendix II), the scientific panel also was asked to give due consideration to the need for data to support the construction of a tropical "Virtual Proving Ground", which will be developed by Yuma Proving Ground on the basis of "Master Tropical Environment Reference Sites". Table 5 presents the summary parameters that define the ideal tropical test environment. Figure 6, combined with the list of most suitable sites from Table 6, provide an further data for developing a model tropical environment. As regards this long-term objective, the primary difficulty envisaged by the panel is that of being able to describe the synergy of processes intrinsic to the parameters that have been selected by the panel to best depict a tropical environment, one of the most complex, variable, and transitory ecosystems in the world. This will be an interesting challenge for the future.

VIII. ACKNOWLEDGMENTS

Ms. Luisa Wong was outstanding in serving as the Tropic Test Center project officer for the site visit and data gathering phases of the project. The members of the panel recognize the invaluable assistance provided by the entire staff of the Tropical Test Center: Rolando Ayala, Oritela De Janon, George Downs, Alcibiades Grajales Jr. and Sr., Alonso Iglesias, Clinton Launsett, Ricardo Martinez, Carlos Moreno, Tamara Paredes, Arianne Perez, John Sargent, Juventino Serrano, Dinorah Tijerino, Jorge Valdez, and back for an encore Roy Blades. Without their support in explaining the tropical

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The panel recognizes the assistance provided by Mr. Lance Vander Zyl and Ms. Valerie Morrill, both of Yuma Proving Ground. Ms. Morrill worked both as a sponsor point of contact for the panel and served as a panel member researching the biological setting. Mr. Vander Zyl contributed the description of tropical testing to the final report and served as an overall resource on the tropical environment. The panel also recognizes the expertise of MAJ Mike Hendricks of the Department of Geography and Environmental Engineering, the United States Military Academy. His geographic information system expertise was the source of the map figures presented in this report.

IX. BIBLIOGRAPHY

Anstey, R.L. 1960. Canal Zone Analogs VI: Analogs of Canal Zone Climate in the Far East. US Army Quartermaster Research and Engineering Center Technical Report EP-9141, 26p.

Anstey, R.L. 1964. Canal Zone Environment - Pacific Sector. U.S. Army Quartermaster Research and Engineering Center Technical Report EP-12, 51p.

Bailey, R.G. 1995. Description of the Ecoregions of the United States Misc. Pub. No. 1391, USDA Forest Service, 108 p. (with separate map at 1: 7,500,000).

Birkeland, P.W., 1984, Soils and Geomorphology: Oxford University Press, New York, 372 p.

Blades, R.E. 1972. Environmental Mapping of Tropic Test Sites Report I: A Comparison of Three Methods for Predicting Vegetation Density in the Humid Tropics. US Army Tropical Test Center Report DTIC AD 903802L. 32Pp.

Blair, W.B., 1958a, Canal Zone Analogs III: Analogs of Canal Zone Climate in East Central Africa. US Army Quartermaster Research and Engineering Center Technical Report EP-142, 24p.

Blair, W.B. 1958b. Canal Zone Analogs V: Analogs of Canal Zone Climate in the Pacific Islands. US Army Quartermaster Research and Engineering Center Technical Report EP-94, 26p.

Blair, W.B. and Chambers, J.V. 1959. Canal Zone Analogs X: Analogs of Canal Zone Climate in Australia and New Guinea. US Army Quartermaster Research and Engineering Center Technical Report EP-113, 26p.

Bloom, A.L., 1978, Geomorphology: a systematic analysis of Late Cenozoic landforms: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 510 p.

Brunig, E.F. 1983. Vegetation structure and growth. pg. 49-75, Chapter. 4 In Golley, F.B. [ed.] Ecosystems of the World 14A. Tropical Rain Forest Ecosystems. Structure and Function, Elsevier Scientific Publishing Co., 381p.

Brownley, C.R., Kline, F., Williamson, R., Dement, W., and Egbert, H. 1985, Relocation of the Tropic Test Center: A Comparison of Puerto Rico and Hawaii. US Army Material Command, Test and Evaluation Command unpublished report TTCR-01, 28p.

Chambers, J.V. 1960. Canal Zone Analogs X: Analogs of Canal Zone Climate in the Pacific Islands. US Army Quartermaster Research and Engineering Center Technical Report EP-142, 30p.

Chambers, J.V. and Blaut, J.M. 1958. Canal Zone Analogs I: Analogs of Canal Zone Climate in Middle America. US Army Quartermaster Research and Engineering Center Technical Report EP-91, 30p. Quartermaster Research and Engineering Center Technical Report EP-87, 20p.

Dickenson, W.R., 1979, Plate tectonic evolution of sedimentary basins, *in* W.R. Dickenson and H. Yarborough, Plate tectonics and hydrocarbon accumulation: American Association of Petroleum Geologists, Continuing Education Course Note Series #1, p. 1-61.

Egan, J.A. and Wang, Z.L., 1990, Liquefaction-related ground deformation and effects on facilities at Treasure Island, San Francisco, during the 17 October 1989 Loma Prieta Earthquake, *in* T.D. O'Rourke and M. Hamada (eds), Proceedings from the Third Janpan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures for Soil Liquefaction, National Center for Earthquake Engineering Research, Technical Report NCEER-91-0001, P. 57-76.

Espenshade, E.B. ed. 1987., Goodes World Atlas, 17 ed. Rand-McNally & Co., 367p.

Faniran A. and L.K. Jeje. 1983. Humid tropical geomorphology. Longman, Inc., 414 p.

Gardner, T.W., Verdonck, D., Pinter, N., Slingerland, R., Furlong, K., Bullard, T.F., and Wells, S.G., 1992, Quaternary uplift astride the aseismic Cocos Ridge, Pacific coast, Costa Rica: Geological Society of America Bulletin, v. 104, p. 219-232.

Geophysics Study Committee, 1986, Active Tectonics, Studies in Geophysics: National Academy Press, Washington, D.C., 266 p.

Golley, F.B. 1983. Ecosystems of the World 14A. Tropical Rain Forest Ecosystems. Structure and Function. Elsevier Scientific Publishing Co., 381p.

Golley, F.B. 1989. Ecosystems of the World 14B. Tropical Rain Forest Ecosystems. Biogeographical and Ecological Studies. Elsevier Scientific Publishing Co., 713 p.

Hamburger, R., Harris, S.K., McCormick, D Swan, S., and Yanev, P., 1993, Guam earthquake of August 8, 1993: EQE Review, Fall, 1993.

Jordan, C.F. 1983. Productivity of tropical rain forest ecosystem and the implications for their use as future wood and energy sources. Chapter 7 in Golly, F.B. (ed.) Ecosystems of the World 14A. Tropical Rain Forest Ecosystems: Structure and Function, Elsevier Publishing Co., pp.117-136.

Jordan, C.F. 1983. Productivity of tropical rain forest ecosystems and the implications for their use as future wood and energy sources. pg. 117-136, Chapter. 7 In Golley, F.B. [ed.] Ecosystems of the World 14A. Tropical Rain Forest Ecosystems. Structure and Function. Elsevier Scientific Publishing Co., New York. 381 p. Mann, P. and Corrigan, J., 1990, Model for late Neogene deformation in Panama: Geology, v. 18, p. 558-562.

Moores, E.M. and Twiss, R.J., 1995, Tectonics: W.H. Freeman and Company, New York, 415 p.

Power, M.S., Egan, J.A., Traubenik, M.L., and Faris, J.R., 1992, Liquefaction at Naval Station Treasure Island and design of mitigating measures, *in* Proceedings, Second Interagency Symposium on Stabilization of Soils and Other Materials, Metairie, Louisiana, p. 2-15 to 2-40.

Reading, A.J., R.D. Thompson & A.C. Millington. 1995. Humid Tropical Environments. Blackwell Publishers, Inc., 429 p.

Ritter, D.F., Kochel, R.C., and Miller, J.R., 1995, Process Geomorphology, 3rd Edition: W.C. Brown Publishers, Boston, 546 p.

Rula, A.A., 1979, Methodology investigation; characterization of test environment, Final Report: US Army Tropic Test Center, AD A113162, p. C1-C9.

Soil Survey Staff, 1975, Soil Taxonomy: US Department of Agriculture, Soil Conservation Service Agriculture Handbook No. 436, 754 p.

Stewart, R.H. and Stewart, R.L., 1980, Geologc map of the Panama Canal and vicinity, Republic of Panama: US Geological Survey Miscellaneous Investigations Series, Map I-1232, scale 1:100,000.

Strahler, A.N. 1967. Physical Geography (John Wiley & Sons), pp.181-208.

Thompson, W.F. 1958a. Canal Zone Analogs II: Analogs of Canal Zone Climate in India and Southeast Asia. US Army Quartermaster Research and Engineering Center Technical Report EP-91, 24p.

Thompson, W.F. 195b8. Canal Zone Analogs IV: Analogs of Canal Zone Climate in West Central Africa. US Army Quartermaster Research and Engineering Center Technical Report EP-93, 22p.

Thompson, W.F. 1958c. Canal Zone Analogs VI: Analogs of Canal Zone Climate in South America. US Army Quartermaster Research and Engineering Center Technical Report EP-97, 24p.

Thompson, W.F. 1959. Canal Zone Analogs VI: Analogs of Canal Zone Climate in Indonesia, the Philippines, and Borneo. US Army Quartermaster Research and Engineering Center Technical Report EP-9116, 22p.

Technical Bulletin, No. MED 575, Occupational and Environmental Health Swimming Pools and Bathing Facilities, US Army, 1993.

US Army Tropic Test Center Report 790401. 1979. Materiel Testing in the Tropics. DTIC AD NO: A072434. 269p.

US Army Regulation 70-38. 1979. Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions.

Wells, S.G., Bullard, T.F., Menges, C.M., Drake, P.G., Karas, P.A., Kelson, K.I., Ritter, J.B., and Wesling, J.R. 1988, Regional variations in tectonic geomorphology along a segmented convergent plate boundary, Pacific coast of Costa Rica. Geomorphology, 1:239-265.

Wiley, S.C., Dodd, A.V., and Chambers, J.V. 1955. Environmental Handbook of Fort Sherman and Fort Gulick, Panama Canal Zone: Analogs of Canal Zone Climate in the Pacific Islands. US Army Quartermaster Research and Engineering Center Technical Report EP-17, 50p.

Williamson, R., Brownley, C.R. and Davis, B.R. 1987a. Relocation of the Tropic Test Center: A Surveys of the Continental United States. US Army Material Command, Test and Evaluation Command unpublished report TTCR-02, 24p.

Williamson, R., Dement, W.A., Downs, G.F. III, and Appel, L.G. 1987b. Relocation of the Tropic Test Center: Surveys of Australian Sites. US Army Material Command, Test and Evaluation Command unpublished report TTCR-03, 27p.

Woodring, W.P., 1957, Geology and paleontology of Canal Zone and adjoining parts of Panama: US Geological Survey Professional Paper 206-A.

APPENDIX I

Scientific Peer Panel for the Tropic Test Center Relocation Study

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APPENDIX II

Request from Director, Yuma Proving Ground to Director Army Research Ofice to Convene a Scientific Peer Panel for the Tropic Test Center Relocation Study

STEYP-TD

MEMORANDUM FOR Dr. Andrew Crowson, Acting Director, ATTN: AMXRO-D, US Army Research Office, P.O. Box 12211, Research Triangle Park, NC, 27709-2211

SUBJECT: Tropic Test Center Location Requirement

1. US Army Yuma Proving Ground (YPG) is an activity dedicated to the test and evaluation of all types of materiel and systems of military interest. One of the key missions of YPG is the test and evaluation of systems in a variety of natural environmental extremes.YPG currently has a variety of environmental test sites located throughout various parts of the western hemisphere representing different environments, including a tropical site located in Panama.

2. Under the provisions of the Carter-Torrijos treaty of 1977, the Tropic Test Center may be forced to relocate elsewhere. YPG is currently negotiating to remain in Panama since the site has proven its worth for tropical testing for over 35 years. We must, however, consider other alternative sites should we fail to negotiate a long term presence to remain in Panama after the year 2000.

3. YPG would like to request the assistance from the Army Research Office to convene a panel to independently evaluate potential sites, including Panama, where tropical environmental testing could be accomplished. Through the years, a number of small studies have evaluated sites ranging from Puerto Rico to Guam to Hawaii to various other sites however none ever completely met the requirement. Typically, most were inferior to our current Panama Site.

4. General considerations would include suitable climate, foliage and other characteristics to adequately challenge equipment and systems in a tropical environment. Preferences would include sites where reasonable infrastructure exists, to support a scientific mission at a reasonable cost, tropical micro environments located within convenient distances to minimize safari costs, and a location in the Caribbean Basin or Central America where over 70% of US tropical military interventions have occurred since 1776.

5. YPG would like to pursue this issue at your convenience and if your activity would assist in this effort we would request a cost proposal so that funding can be provided to accomplish the review. The POC's for this effort will be Mr Lance Vander Zyl (520-328-2124, lvanderz@yuma-emh1.army.mil) or Mr Graham Stullenbarger (520-328-6679, stullenbarger@yuma-emh1.army.mil).

James L Wymer
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